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CONTENTS

ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	kg	kilogram
cm	centimeter	kN	kilonewton
cm/min	centimeter per minute	lb	pound
cm/s	centimeter per second	m	meter
cu ft	cubic foot	m/min	meter per minute
cu m	cubic meter	mg	milligram
°F	degree Fahrenheit	mg/cu m	milligram per cubic meter
ft	foot	mm	millimeter
ft/min	foot per minute	µm	micrometer
gal/min	gallon per minute	µm/s	micrometer per second
hp	horsepower	pct	percent
Hz	hertz	s	second
in	inch	rpm	revolution per minute
in/s	inch per second	W	watt
kHz	kilohertz		

BUREAU OF MINES COAL CUTTING TECHNOLOGY FACILITIES AT THE TWIN CITIES RESEARCH CENTER

By Wallace W. Roepke,[1] Carl F. Wingquist,[2] Richard C. Olson,[3] and Bruce D. Hanson[4]

ABSTRACT

Research on coal cutting at the Bureau of Mines Twin Cities Research Center (TCRC) has evolved from a purely mechanical approach, specifically to reduce dust or frictional methane ignitions, into an understanding of the complexity of the cutting system relationships. Achieving an understanding of these relationships requires a wide variety of testing techniques and equipment. Laboratory facilities and the associated equipment exist for shallow to deep cutting in both coal and coal-inclusive rock with any desired bit type. Research efforts with this equipment are providing insight for significant advances to help solve the problems of pneumoconiosis and frictional ignition. This effort will ultimately affect both respirable dust and methane ignitions at the face through better bit design and will increase the salable percent of run-of-mine (ROM) coal processed. It will also affect the design of rotary-drum cutting continuous mining machines (CMM) and longwall machines.

This report describes the main features of the coal cutting research facilities at TCRC.

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INTRODUCTION

The Federal Coal Mine Health and Safety Act of 1969 with revisions in 1977 was enacted to insure healthier and safer working conditions. One requirement, that airborne respirable coal dust not exceed 2 mg/cu m, is intended to reduce the incidence of pneumoconiosis or "black lung" in coal miners. The enactment of this legislation, with its subsequent monitoring and enforcement by the Mine Safety and Health Administration, required that the Bureau of Mines and others in the mining community better understand the mechanisms involved in generation and control of respirable dust. Accordingly, a continuing Bureau research program established in 1969 has three broadly defined tasks directed specifically to pneumoconiosis: (1) control of primary dust generation by cutting action, (2) secondary control of airborne dust, and (3) dust measurement instruments.

Despite considerable insight into the dust problem and the body of opinion about the topic that existed before the Bureau's effort, no research data were available to specify the relation between the cutter(s) and respirable dust. Previous research was task oriented and did not cover the cutting system,[5] thus no relationship was drawn between the cutting system and the total system. It has become apparent over the past several years that no single variable (e.g., dust, ignition, or wear) can be individually analyzed and yield usable results for direct field application. Accordingly, the TCRC laboratory incorporates all aspects of cutter testing and is thus a fully integrated facility that addresses both health and safety.

[5]The cutting system is defined herein as the cutter-mineral interface with all those variables affecting it: dust, wear, methane ignition, forces, cutter geometry, speed, etc. The total system is herein defined as the elements from the face through the preparation plant that support the cutting system.

The original work at the Bureau's Twin Cities Research Center refined previous field efforts (1, 6)[6] and provided laboratory confirmation that the reduction of dust came from a reduction of cutting energy (9-19). Additionally, the early efforts analyzed existing drum-type cutting by CMM's (14). This early work indicated that a total cutting system design that correctly used coal cutting tools would substantially reduce respirable dust and frictional methane ignition.

Those initial efforts have since been expanded to include the full spectrum of cutting system parameters. Testing can be done with either conical and radial cutters for CMM or larger longwall cutters on both coal and coal-inclusive rock. The test variables may include interactive or independent cutting bit forces, depth of cut, angle of attack, angle of skew, bit lubricity, primary respirable dust generation, symmetric and asymmetric bit wear, bit impact failure, and frictional impact ignitions. Only the facilities for these activities are described in this publication. Details of experimental designs, testing techniques, and research results may be found in the Bureau references listed. This research is looking at the fundamentals of the cutter-mineral interface and cutter design to solve specific problems of primary dust generation and frictional ignitions. It is long-term research and, as demonstrated by a number of patents on machine design (9, 15-17), may ultimately modify the equipment or the cutting method to reduce the problems. The following discussion is intended to provide researchers, particularly those who are just becoming involved in rock and coal cutting research, with some insight into what is involved in setting up a comprehensive test facility. Researchers in the private sector may also find it helpful in identifying areas of mutual interest for possible cooperative efforts.

[6]Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

FACILITIES DESCRIPTION

The equipment in the coal cutting technology laboratory is in two separate buildings (figs. 1-2) in the Fort Snelling area of the Twin Cities Research Center. The smaller building contains only the system for frictional ignition testing, to isolate the potentially dangerous explosion area. The larger building area contains sample preparation and storage facilities and all the other test systems. A general description is given in this paper of the equipment in each of these areas.

The research in the laboratory includes several areas, which sometimes overlap. At present these are cutting forces in three orthogonal axes, primary

FIGURE 1. - Coal cutting test facility building.

FIGURE 2. - Methane ignition test facility building.

airborne respirable dust generation, bit impact failure, bit wear, and bit ignition potential in methane-air during cutting. Bits with various geometries and from various manufacturers in both new and used condition are used for the tests. Additional ancillary test programs include water-bit lubrication, impacting bit, rotary bit, interface temperatures during abrasion, new bit materials, and new bit designs.

TEST EQUIPMENT

The major equipment components include a small, horizontal, class C mill, a large planer mill, a large vertical shaper, a small research mining machine retrofit for multiple bit linear cutting (microminer), a small, portable, in-seam tester (linear cutter) for in situ tests, and a narrow rotary-drum-bit ignition test stand.

Ancillary support equipment includes multichannel recorders, strain-gaged plate and quartz crystal dynamometers, normal and high-speed 16- and 35-mm photographic equipment, video recording equipment, programmable sample table stepping controllers, data acquisition systems, several optical particle counters and/or sizers, several ionizer particle counters, one piezo mass balance particle sizer, one electrical aerosol analyzer, 30 personal samplers, a 100-W CO_2 laser with power meter and pulse control, two radiometers, and other miscellaneous electronic equipment.

SMALL LINEAR CUTTING SYSTEM

The small linear cutting system with its associated Hewlett-Packard (HP)[7]

[7]Reference to specific products does not imply endorsement by the Bureau of Mines.

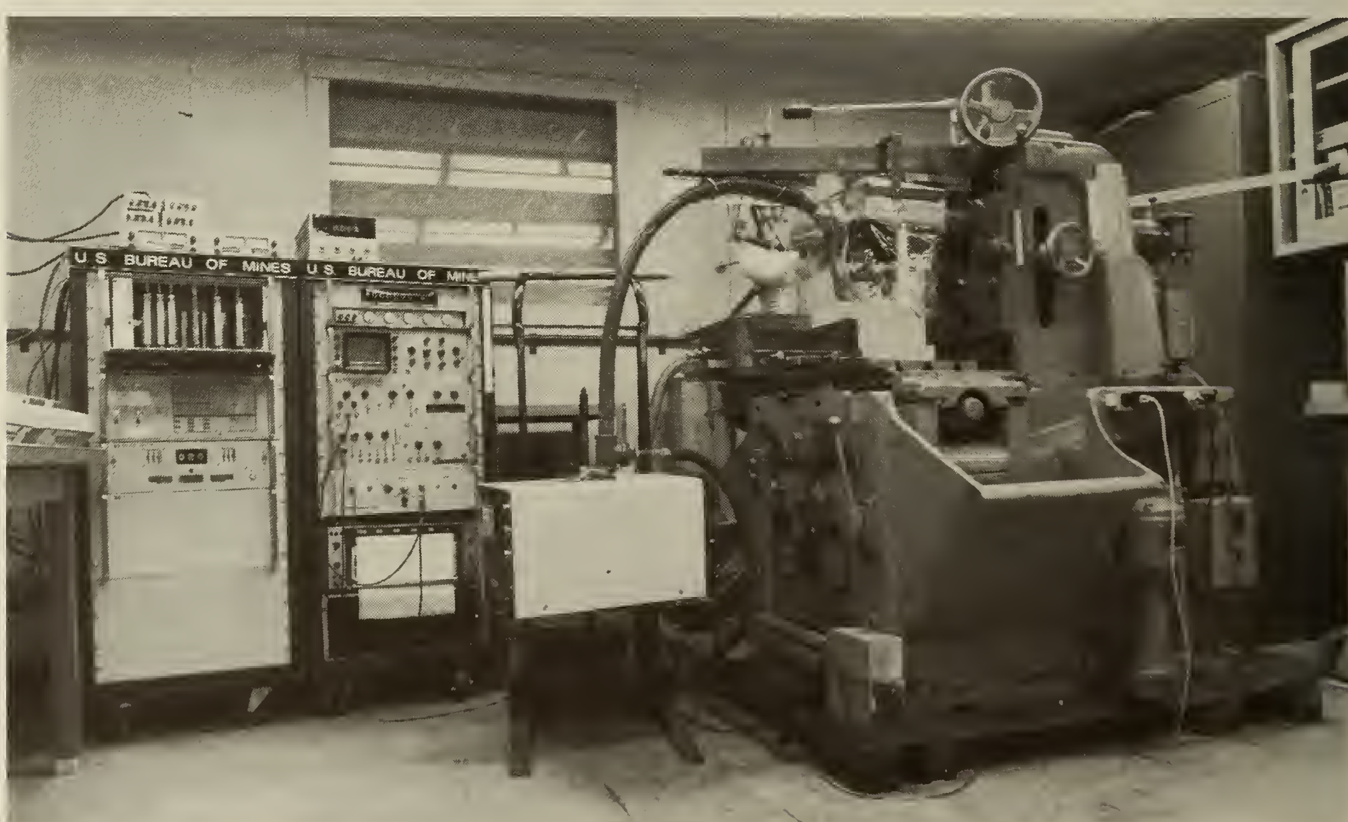

FIGURE 3. - Small linear cutting system.

data acquisition system is shown in figure 3. It is a modified, horizontal, simplex, class C mill with the following capabilities:

1. Maximum sample size: 33 cm wide by 25 cm long by 20 cm high.

2. Traverse rate: 0.04 to 1.7 cm/s.

3. Maximum depth of cut: 3.8 cm (1-1/2 in).

4. Peak forces: 18 kN (4,000 lb).

It has a three-axis plate dynamometer, strain-gaged for X, Y, Z forces.

The test bit is rigidly fixed to the dynamometer so the sample traverses under the bit. The arrangement for clamping the samples to a holder on the mill table is shown on the left in figure 4. Also shown, on the right, are the bit and the dust transport tube. This tube and the particle sampler are shown more clearly to the left of the cutter system in figure 3. A typical test cut with a conical bit is shown in figure 5.

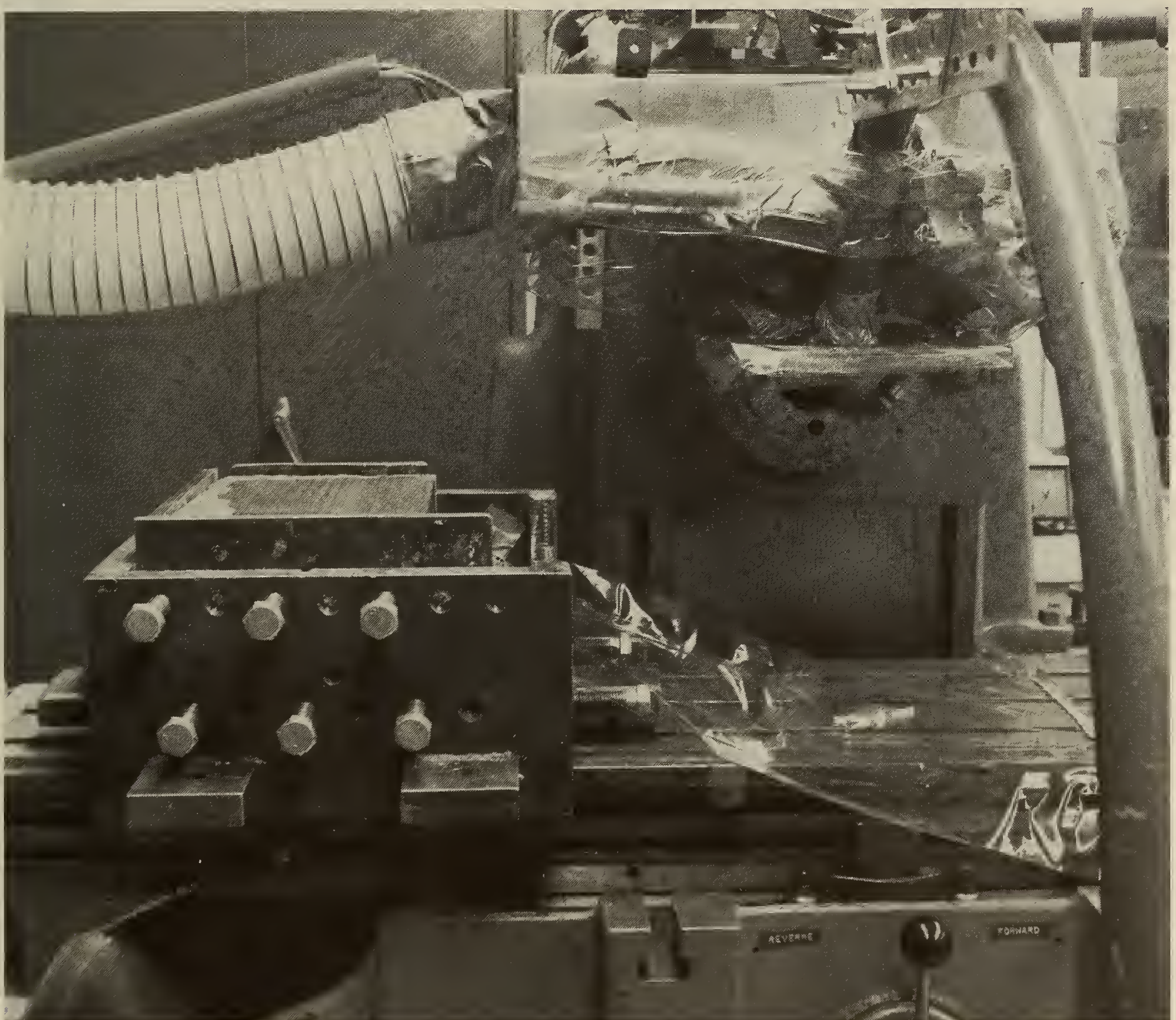

FIGURE 4. - Uncut sample mounted in place.

FIGURE 5. - Cutting in sample.

The bit mount-dynamometer configuration is on the horizontal arms of the mill head, which permits the bit position to be varied laterally 22.9 cm (9 in) across any sample face. Depth of cut is adjusted by vertical displacement of the mill head, since the horizontal arms that hold the bit's dynamometer can be moved up or down. The operating specifications of this mill are listed in the appendix.

Bit forces are fed through, and measured by, a three-axis, strain-gaged, plate dynamometer which responds to lateral, normal, and cutting forces. Signals from the three bridge circuits are fed to a hardware-controlled, HP data acquisition system. This system is capable of high resolution (six-digit) measurements at relatively low speed (30 channels per second). The system is adequate for bit-force data whenever the cutting speed is relatively low (i.e., <10 cm/min), and the signal bandwidth is accordingly narrow. The validity of testing at such low speeds is based on the fact that rock response to cutting is independent of speed within the range bounded by rate of creep on one end and rate of fracture propagation on the other.

Dust produced by cutting is sampled just above the bit and carried by a low-loss tube through an isokinetic sampler to a modified Bausch & Lomb optical particle counter (OPC). The OPC outputs, for each particle passing through its viewing area, a pulse whose amplitude is proportional to the particle's diameter. An HP multichannel analyzer (MCA) accepts the pulses as input and sorts them into classes to produce a size distribution histogram.

LARGE LINEAR CUTTING SYSTEM

The large deep linear cutting system is shown in figure 6. It is a planer mill which has been modified by removing the quill head and motor from the overhead rail and replacing them with a rigid mount to support the bit-dynamometer hardware. This overhead rail permits great flexibility in testing. The test area of the system is shown in figure 7. The bit-dynamometer mounting may be translated laterally across the total open throat distance of the table (176.6 cm); the rail has a vertical displacement from 7.6 to 111.8 cm above the table. The wide throat, large, vertical clearance, and large table area (106.7 cm wide by 152.4 cm long) provide tremendous flexibility on sample size.

The long-way guides of the bed on which the table moves permit the table to be moved totally out of the throat area of the machine. A forklift or overhead hoist helps large sample handling. The center of figure 7 shows the test bit shrouded by plastic to eliminate background dust. In the lower right corner one of the sample holders is shown clamped to the traverse table with the backing supports in place. The large tube above the shrouded bit brings clean

FIGURE 6. - Large deep cutter.

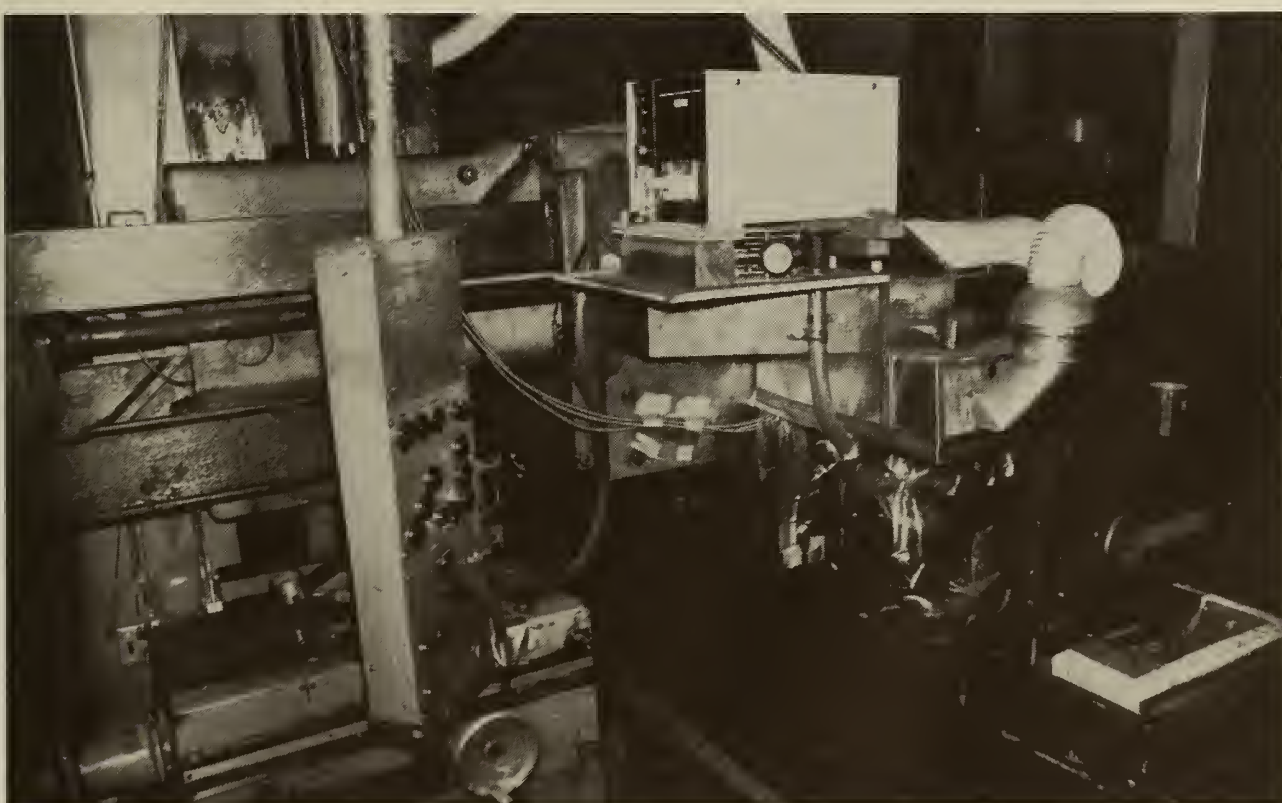

FIGURE 7. - Test area of large cutter.

FIGURE 8. - Inner shroud around bit and dust sample part.

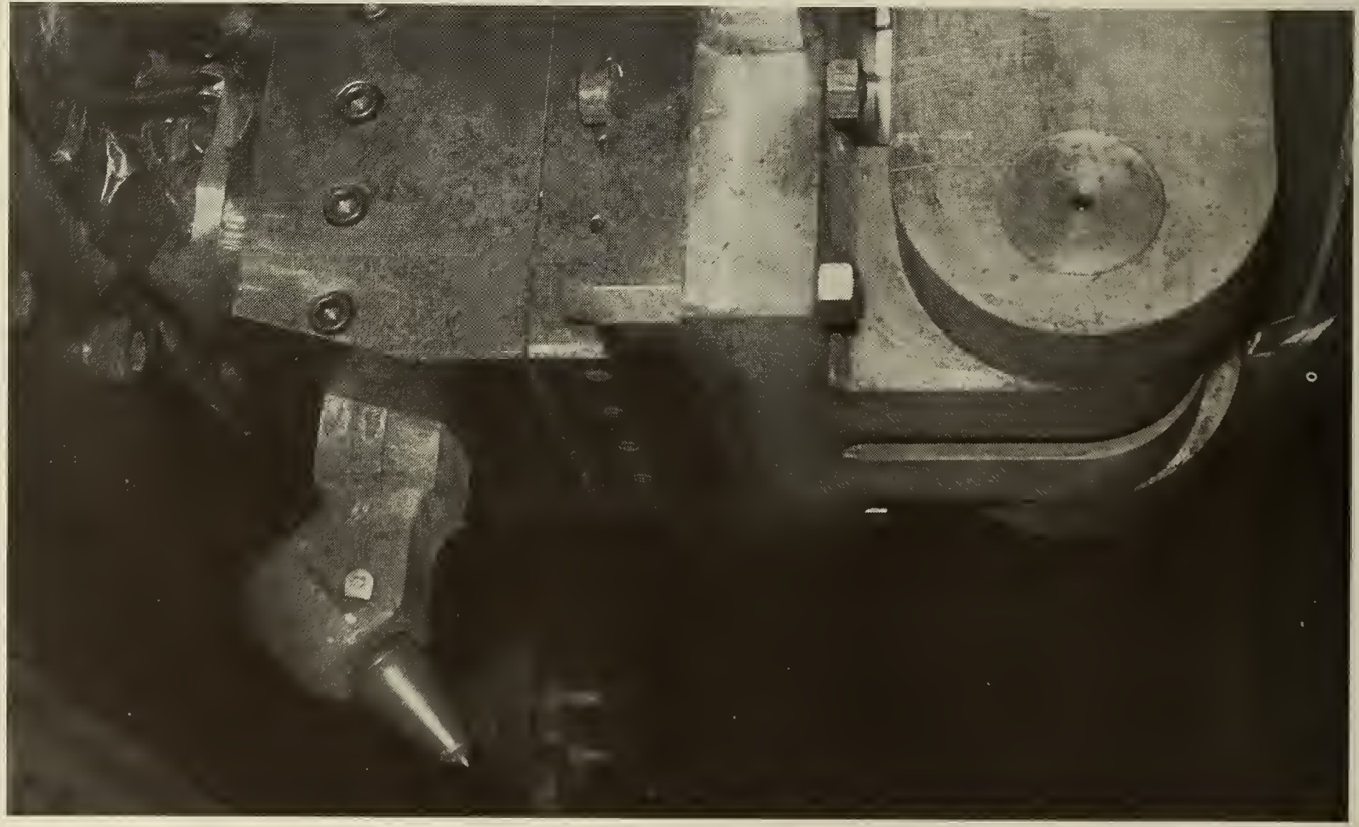

FIGURE 9. - Bit-dynamometer configuration on large cutter.

air into the outer shroud around the test area. A smaller, inner shroud surrounds the bit-coal test path (fig. 8). The optical particle-size pickup is mounted just above the cutting bit inside the inner shroud. The sampler itself, shown to the left of the clean air tube at the top center in figure 7, can cover a range from 0.2 to 20 μm; the used range is 0.2 to 8 μm in five class intervals.

A closer view of the bit-dynamometer configuration with the shrouds removed is in figure 9. The bits are mounted on 5.08-cm-square posts 25.4 cm long which are clamped inside the dynamometer housing; a bit is shown mounted in the left half of the figure. Additional bit-post configurations, in figure 10, give some idea of the adaptability of the system. The dynamometer is bolted to the support system shown in the upper right half of the figure. The support system has a 5.08-cm-diam hinge pin which permits the bit-dynamometer package to be rotated for varying attack angles. Several coal samples, after testing with this system, are shown in figure 11.

The bit force dynamometer is a commercially built (Kistler) unit containing six pairs of one- and two-component, piezoelectric, force transducers which respond in three mutually perpendicular directions. (See the appendix for the complete specifications.) The dynamometer outputs are connected to the charge amplifier by low-noise, armored, coaxial

FIGURE 10. - Bit mounting posts for use with dynamometer.

FIGURE 11. - Samples after test cuts.

cables. Voltage signals from the charge amplifiers are then input to the data acquisition system which may be the HP system described above but is more often a Digital MINC (Modular Instrument Computer) system configured to condition, digitize, process, and store the data. A description of the Digital system itself will be found later in this report.

The optical particle counter and multichannel analyzer described previously are used to analyze the dust sampled.

IGNITION-WEAR-IMPACT FAILURE TESTING

Both the small and large horizontal, linear cutting systems are used to measure primary respirable dust and orthogonal cutting forces, but these systems do not have an automatic cycle for bit-wear tests. Two appropriate systems are available. One is a constant-depth, vertical, linear cutter, and the other is a narrow rotary-drum section of a CMM. Since wear is so closely associated with frictional heating and ignition

potential, the ignition test facility includes the rotary wear facility.

Vertical Cutting Linear Tester

The linear wear tester shown in figure 12 is a modified large vertical slotter (or shaper). This system has several different sample-holding configurations. The one in figure 12 is easy to use but measures normal force only. Figure 13 is a closer view of a fully instrumented system that measures orthogonal forces and rotary bit motion during cutting. This system requires substantially more time per test set owing to its complexity. The amount of data recovered with it also requires sophisticated, ancillary equipment.

In the vertical test system the bit is mounted on the ram, which moves while the sample is stationary. The sample test face and bit configuration after testing are shown in figure 14. A closer view of the bit-mounting configuration is shown in figure 15. The potentiometer at the back end of the bit mounting block is part of the bit-rotation measurement package.

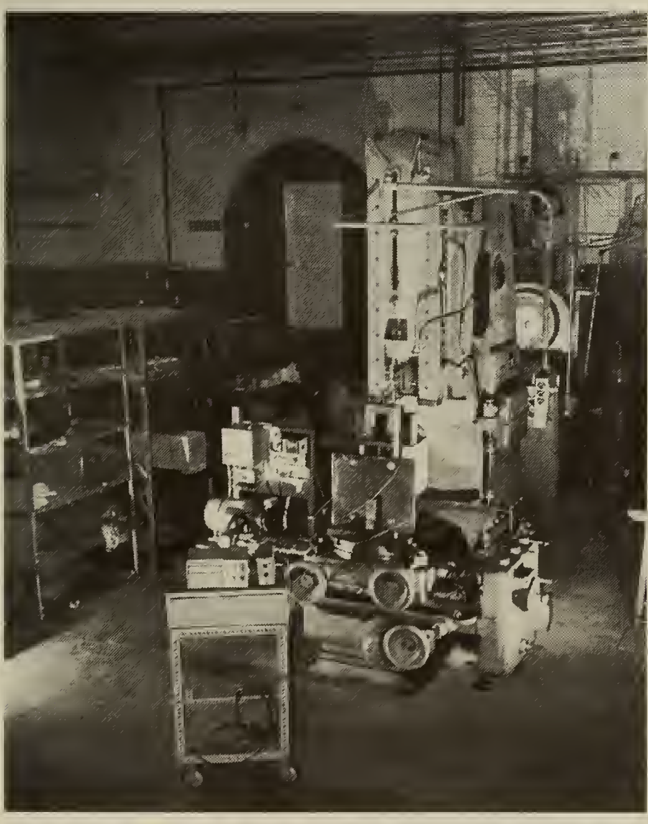

FIGURE 12. - Full-frame shot of shaper.

Several additional bit-holder configurations are shown in figure 16 to demonstrate flexibility on (from left to right) attack angles, skew, and/or bit type. The tool post holder in which a bit and block are mounted automatically retracts the bit at the end of each pass so the bit is not dragged in reverse through the test sample on the return stroke.

The slotter table has been modified to permit automatic stepping up to 5.08 cm between test cuts. This automatic-stepper control system is shown in figure 17 at the left side of the fully instrumented, sample-holding fixture. A reversing feature has been incorporated in the automatic cycle so at the end of any set of face cuts the system pauses one stroke after the last cut, the sample is automatically stepped forward to establish the required depth of cut, the table reverses itself, and the testing continues in reverse across the face. The procedure automatically continues in this manner back and forth across the face, using predetermined spacing and depth of cut, until the programmed number of cuts has been made. With this system long-term wear testing may be conducted unattended. Since wear only occurs with harder inclusive materials, this system is not used for cutting clean coal and, therefore, has no dust sampling attached to it. It would be easy, however, to shroud the test area and obtain dust samples should it ever be worthwhile.

Force in general, but especially normal force, has been shown to change rapidly with wear (4, 10). Therefore this system has been designed to measure either normal force alone, when easy and rapid testing is desirable, or orthogonal forces, when a complete data set is necessary. The sample mounts are gauged, not the bit holder, as on the previously described systems. The fully instrumented sample holder has been designed to use four, triaxial, quartz-crystal load

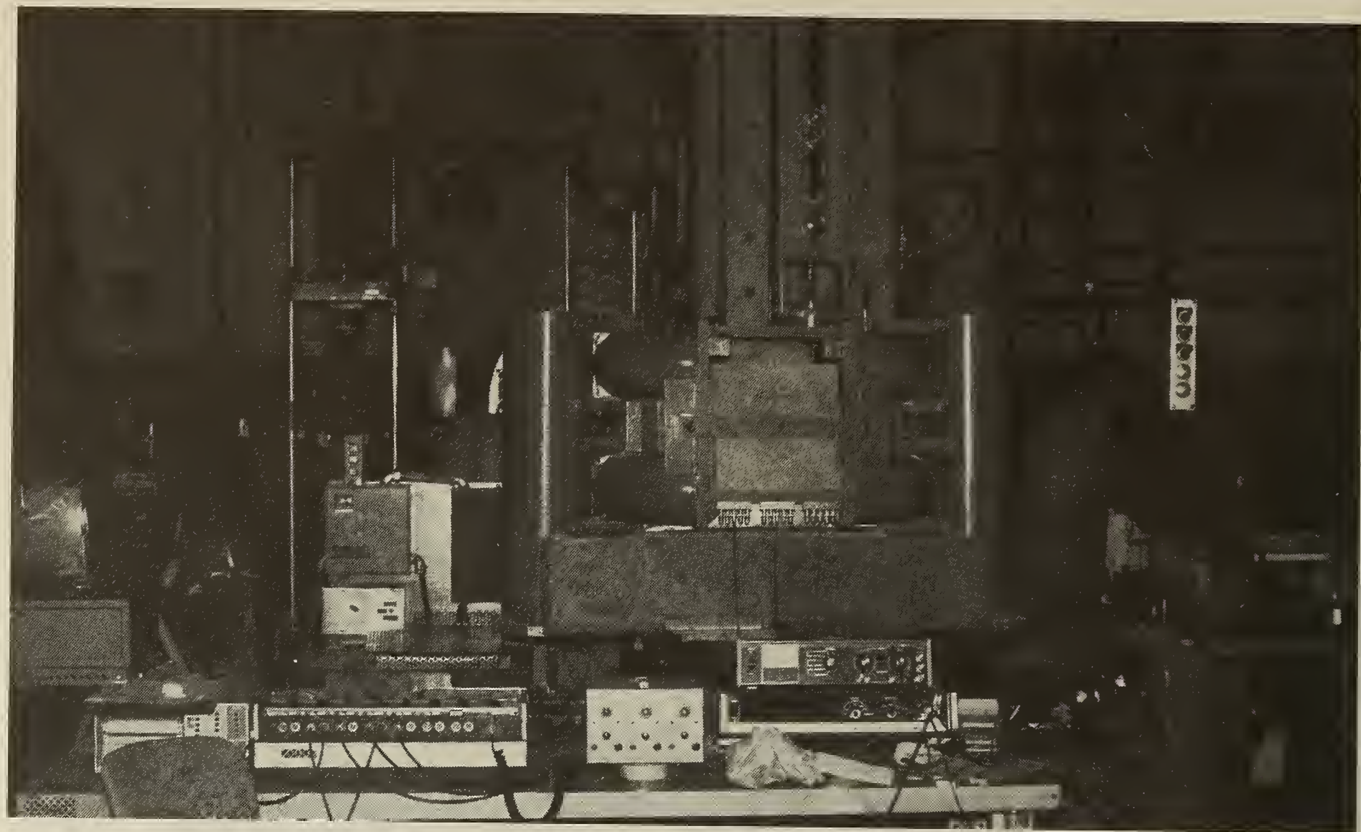

FIGURE 13. - Fully instrumented sample holder on vertical shaper.

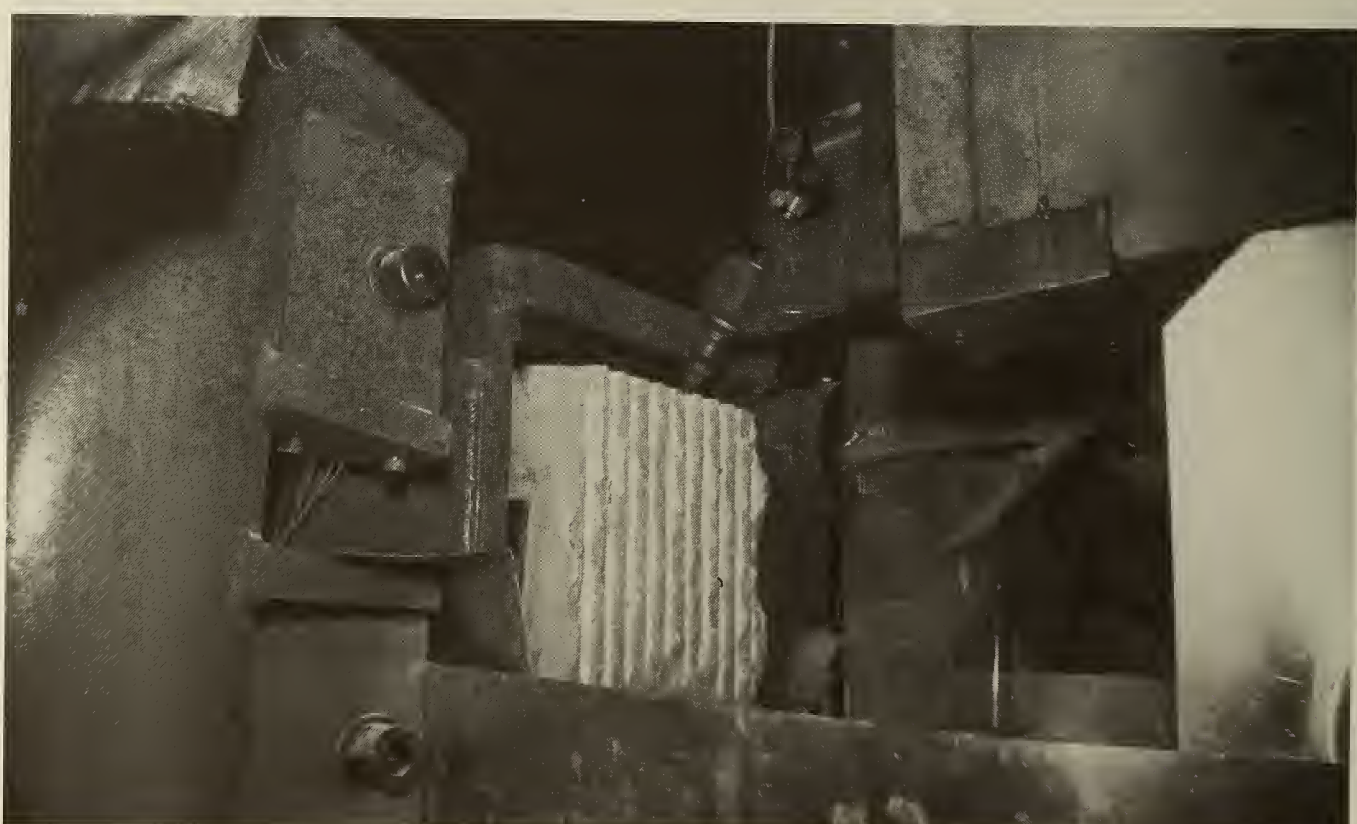

FIGURE 14. - Sample test face-bit configuration.

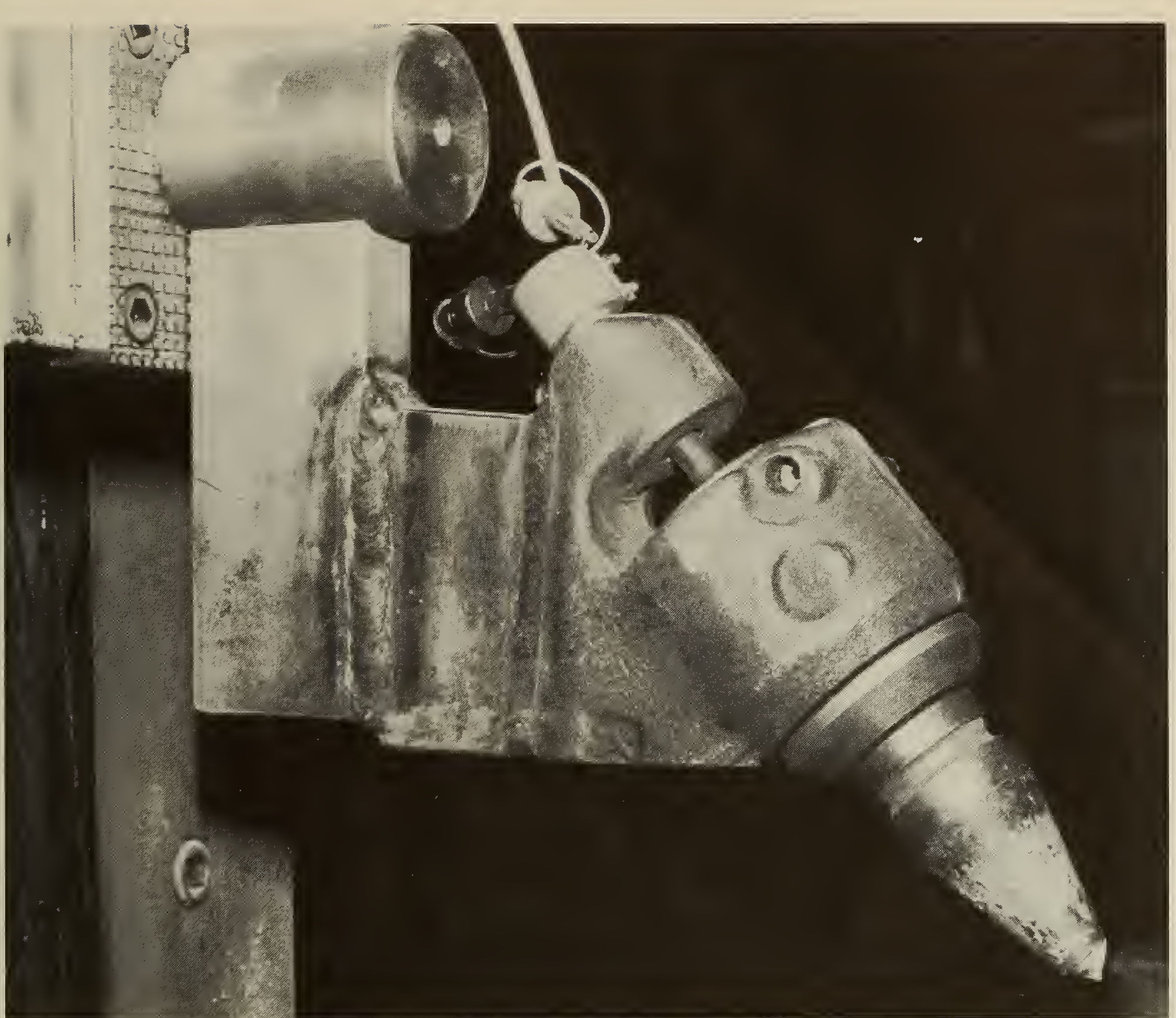

FIGURE 15. - Close view of bit-mount configuration.

cells mounted between the four supporting arms of the sample holder and the four support plates on the table's mounting frame. The design keeps the load cells within ±5.08 cm of the plane of the bit-mineral interface to limit torque loading on them. Two of the support plates may be seen on the left in figure 17, and the inside edges of two of the support arms are at the right center of the same figure. The loads cells are captive between these four points.

The X, Y, and Z outputs from the load cells are summed (connected in parallel) to yield the lateral, cutting, and normal bit forces, respectively. Because of the relatively high cutting speeds of this machine, the frequency content of the bit force signals can reach 1,000 Hz or higher. Therefore, to achieve high-fidelity data recording, a multichannel, FM tape recording system is employed. By recording at high tape speed and replaying at a low speed, the time base is expanded, making it possible to produce accurate strip chart recordings. By expanding this time base, the speed limitations of the data acquisition system (MINC) are also overcome. Several additional data tracks are available for recording other quantities such as bit rotation, dust

FIGURE 16. - Typical bit-holder configurations.

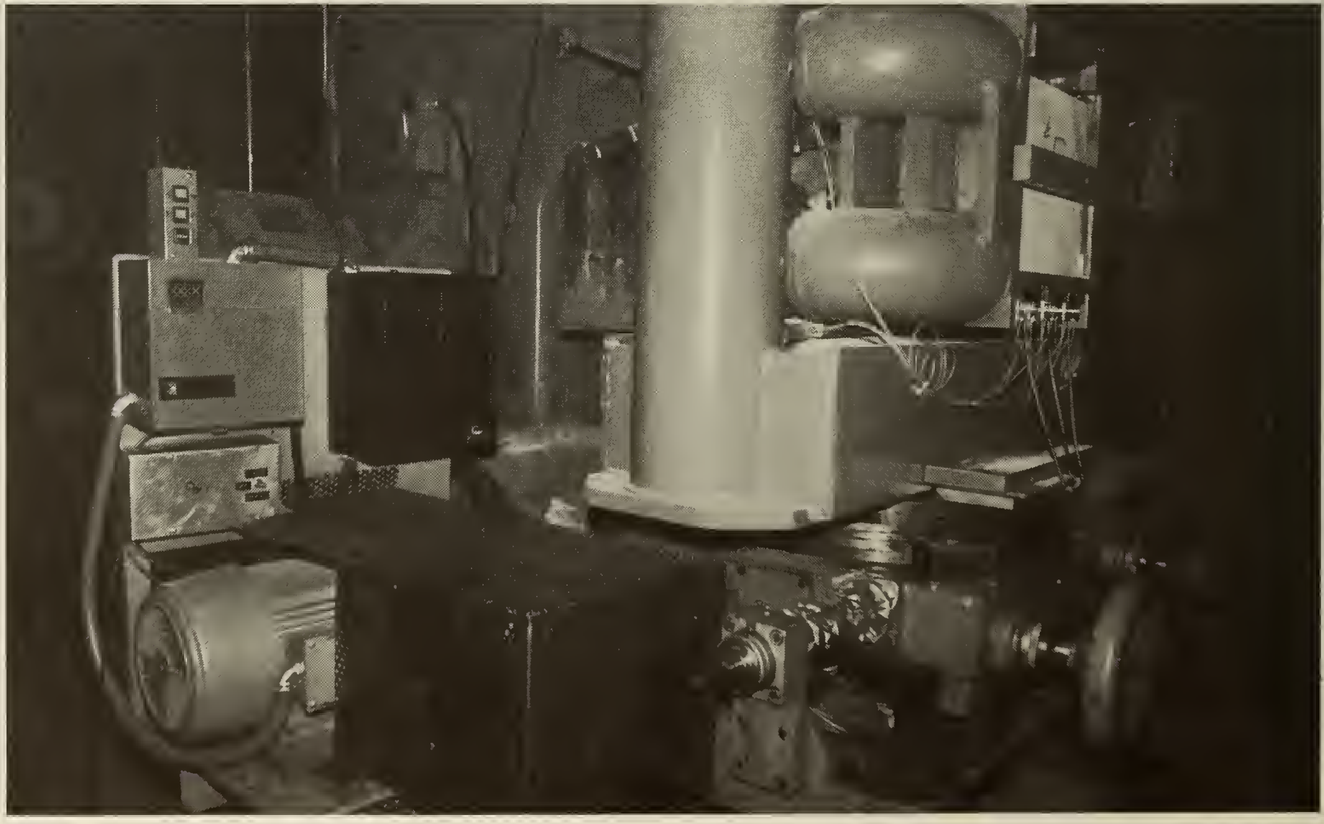

FIGURE 17. - Automatic stepping equipment.

concentration, acoustic noise, and bit-rock interface temperature. The latter measurement is through a high-speed (10μs response) noncontacting radiometer which covers the range from 800° to 3,000° C.

Rotary Drum Wear-Ignition Tester

The rotary wear facility is shown in figure 18. This system has a multiple use since it incorporates wear, impact failure, and ignition testing in the same facility. The major components in the system are the full 86.36-cm (tip-to-tip) drum section and the sample mounted on an automatic, remote-controllable X-Y table. Not shown in this figure, but directly behind the chamber on the left, are a motor and pump for driving four motors mounted on the drum section. Two of the motors may be seen on the left in figure 18. The other two, out of view, are on the opposite side of the drum. Figure 19 shows the control and instrumentation system in an adjacent room. The test facility has the following specific capabilities:

1. 100-hp, 100-gal/min pump and motor driving four Staufa motors on a 15.2-cm-wide, single-bit row; 86.4-cm-diam CMM drum section rigidly mounted to the chamber base.

2. 0- to 100-rpm infinitely variable drum speed.

3. Maximum sample size of 2.832×10^{-2} cu m (1 cu ft).

4. Sample mounted on an X-Y base power driven in each axis by stepper motors programmable and remotely operated from the control room.

5. 0- to 0.95-cm/s advance rate to move sample into bit in Y-axis for increasing arc length-kerf depth tests.

6. 0- to 4.45-cm/s lateral rate to translate sample past bit in X-axis for constant arc length-kerf depth tests.

During all methane ignition, impact failure, and wear testing, it is routine instrumentation procedure to monitor cutting (tangential) force, work performed per impact, cutterhead speed; and for ignition testing, percent CH_4 in the test chamber is also monitored. These data are recorded on a multichannel strip chart recorder.

Cutting force is recorded from a differential pressure transducer connected across the hydraulic motors that drive the cutterhead. The pressure drop across the motors is related to the torque at the cutterhead. This relationship has been established by calibration with a load cell.

Work performed, or energy absorbed per impact, is determined by electronically taking the time integral of the cutting-force signal and multiplying this result, the impulse, by the cutting radius and angular velocity of the cutterhead.

Angular velocity, or revolutions per minute, is monitored by a magnetic gear-tooth sensor in proximity to a drive gear. The sensor's pulse output drives a frequency-to-dc converter, which in turn drives an rpm-scaled meter and a recorder pen.

Methane concentration is monitored continuously by a methanometer within the test chamber. This sensor is basically a wheatstone bridge in which the temperature and, therefore, the resistance of one of the arms depend on the concentration of methane in the atmosphere. The bridge signal is amplified to drive a meter movement and one channel of the recorder.

During any test the cutter tool mounted on the drum section rotates at the set speed. The sample is then stepped into the cutter at a predetermined advance rate for an increasing kerf depth and length, i.e., trimming top rock (fig. 20), or set to a certain depth and stepped across the face of the drum for multipass, constant kerf depth and length cutting, i.e., sumping along top rock (fig. 21). When the system is being used for bit-impact failure tests, only half

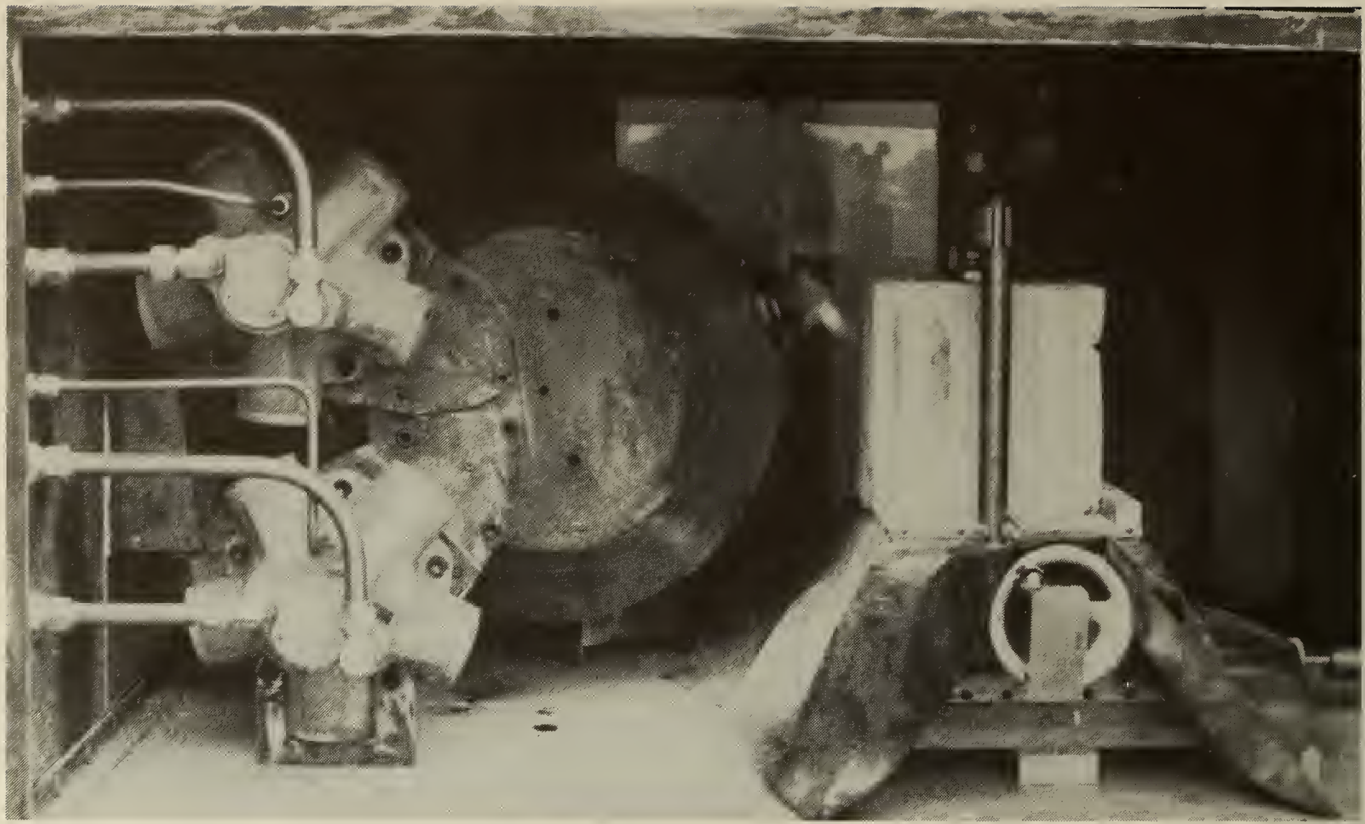

FIGURE 18. - Rotary test facility showing drum and sample.

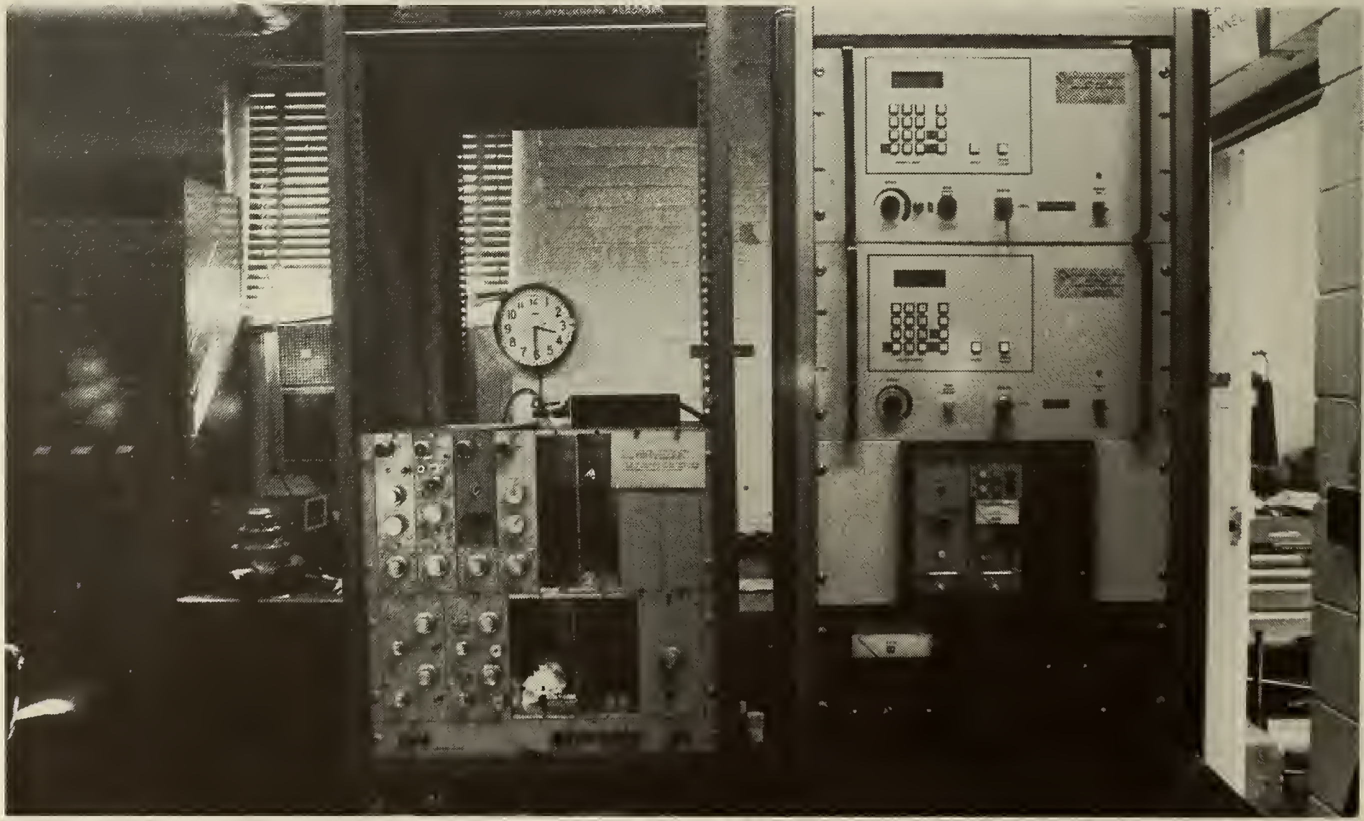

FIGURE 19. - Control room with instrumentation for ignition testing.

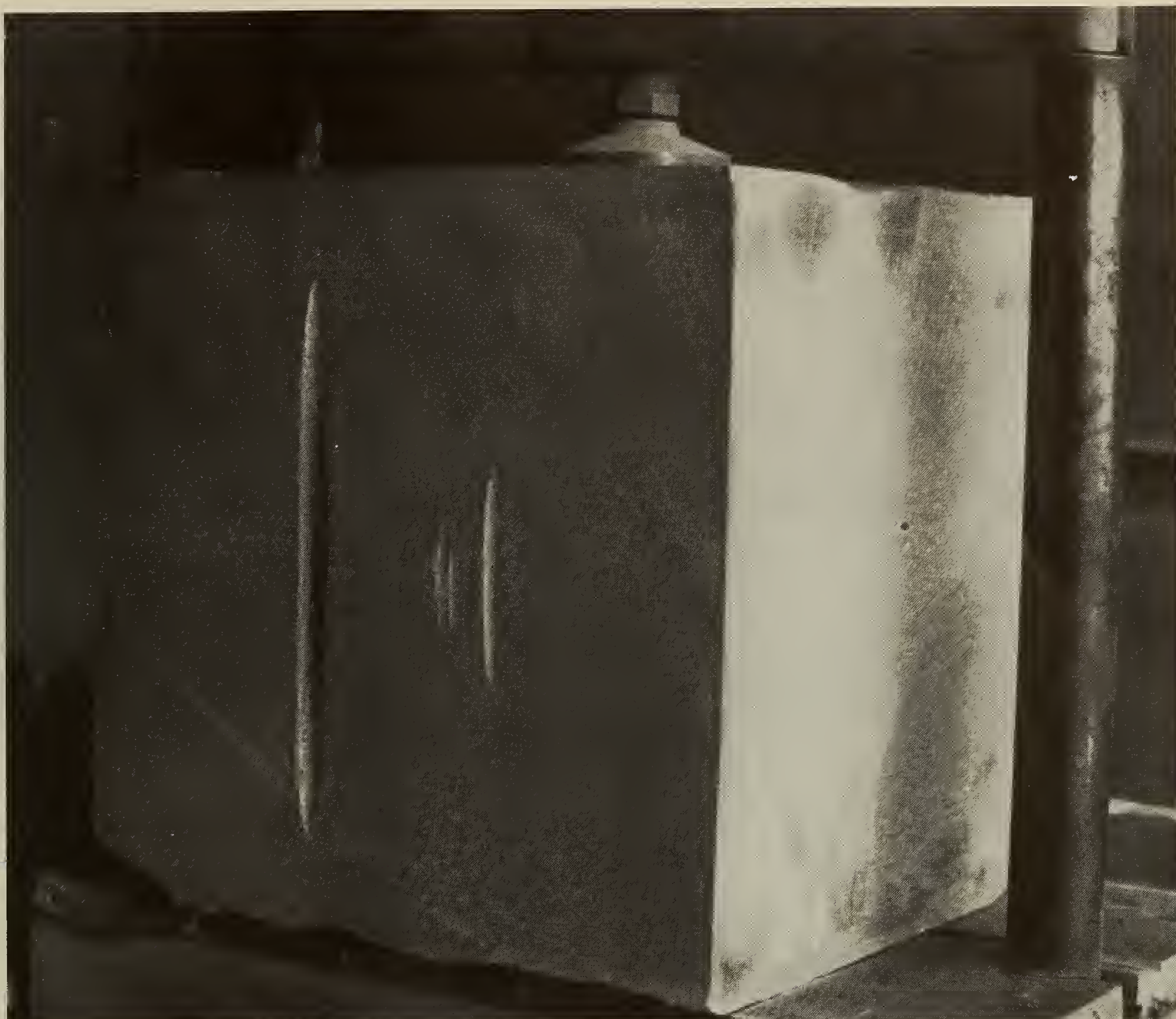

FIGURE 20. - Sample face showing increasing kerf length (i.e., trench cut with fixed depth of advance, same cut each pass).

the sample height is used so the bit will impact the top face of the sample at maximum depth of cut, i.e., to simulate the middle band material. For wear testing, the system may be set to automatically cycle back and forth across the test face in the same manner as the vertical slotter until a set number of cuts have been made at the preset depth and spacing.

For use as a frictional ignition facility, the chamber is sealed across the open side with polyethylene sheeting, an easily ruptured diaphragm that quickly vents the chamber on ignition. Ignitions are vented harmlessly to a fenced area outside the building. Figure 22 shows the chamber just a few milliseconds after an ignition with the diaphragm already rupturing along the bottom edge. Results of recent bit ignition tests may be found in references 3 and 7.

LARGE SAMPLE TEST BAY

The large sample test bay with the microminer in place is shown in figure 23. The bay is constructed of 30.48-cm

FIGURE 21. - Sample face showing constant-kerf-length tests (i.e., transverse cut with fixed depth of cut, new cut each pass).

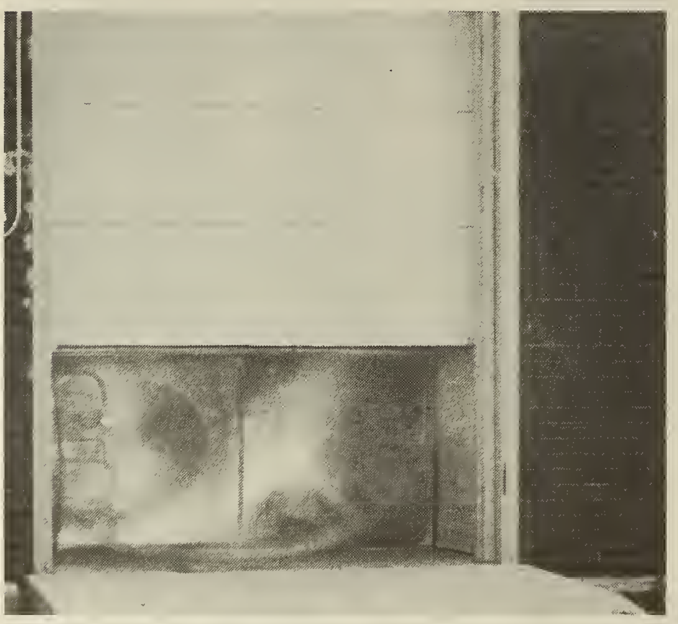

FIGURE 22. - Frictional ignition test chamber milliseconds after frictional ignition.

structural I-beams with horizontal beams cemented in the floor between the uprights in the same manner as the top crosspieces to form a box shape. Such an arrangement provides stability for locking the microminer or any other test apparatus in place during tests. The sample support section, shown on the right side of figure 23, has two horizontal crosspieces mounted between U-shaped brackets on the uprights and held by 5.08-cm pins. These provide the backing for the normal forces imposed upon the sample during cutting. The horizontal cutting force is supported by the steel beam in the floor to which the uprights are welded.

A simulated coal material has been developed for this test bay since it is not practical to obtain coal in the sample size necessary. A complete description of this synthetic material is contained in a following section.

Although respirable dust measurements cannot be directly obtained from the simulated sample, relative differences can be obtained by shrouding the entire test bay and mounting a quick response sampler inside the cutting area. To obtain cutting forces either the test equipment or the sample support system must be instrumented. This large test bay is presently used with two systems: the linear cutting retrofit microminer and the in-seam tester.

Microminer Multiple-Bit Linear Cutter

The original research microminer (6) has been modified by replacing the narrow, rotary drum section (now being used in the ignition-wear test facility) with a multiple-bit head which makes linear cuts (fig. 23). The machine is designed for deep linear cutting with multiple bits. One of the bit mounts is instrumented to obtain orthogonal cutting forces. In use, the machine is trammed and locked into position in the test bay by front and rear roof jacks. The rear roof jacks have a canopy to cover the operator's station. In the bay these roof jacks are set against the cross beams that simulate the top and lock the machine in place. The bit-block mounting combination is designed for a maximum 12.7-cm depth of cut over a maximum vertical distance of 198 cm.

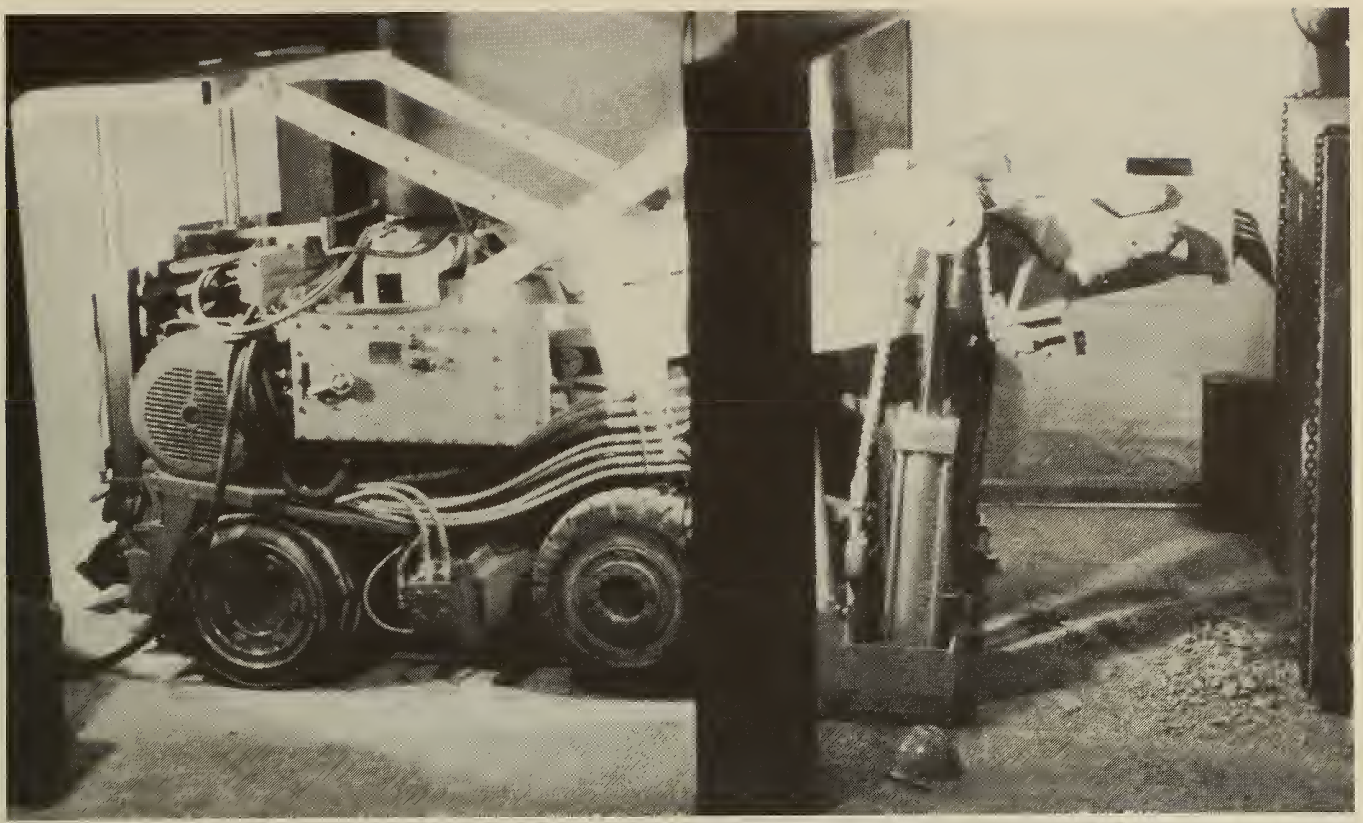

FIGURE 23. - Microminer in large sample test bay.

Bit force instrumentation consists of three strain-gaged clevis pins which attach the bit mounting block to the four-bar linkage that retracts and extends each bit. The bridge outputs are resolved into components of normal and cutting force and summed electronically. The data are available as analog outputs or digitally in binary coded decimal (BCD) form.

In-Seam Tester

The in-seam tester (IST) (fig. 24) is a Bureau-developed portable device that can be carried to an underground face for measuring orthogonal cutting forces in situ (fig. 25). Additionally, the device has a shroud that can be used with a rapid-response optical particle sizer to obtain primary dust data. This total system provides direct laboratory-field test correlation since portability takes it to any environment. An underground face after cutting with the IST is shown in figure 26. Specifications of the unit follows:

Assembled size:	
Length......................	50 in.
Width.......................	18 in.
Height......................	42 in.
Assembled weight.............	250 lb.
Hydraulic power required at 1,500 psi:	
Face preparation............	10 hp.
Test cuts...................	2 hp.
Power for instruments.........	Battery
Maximum cutting force.........	3,000 lb.
Maximum cutting length........	20 in.

Additional supporting equipment (packing cases, spare parts, hydraulic rotary impact drill, etc.) adds 250 lb to the total system. The heaviest single item, the cutter with hydraulic cylinder and supporting structure weighs 150 lb.

Bit forces are fed to the support structure through a splined shaft instrumented with strain gages to measure normal and cutting force. A portable data acquisition system digitizes and stores the data, which are then read

FIGURE 24. - In-seam tester in use underground.

out as a time-at-load-level histogram. Energy, mean force, and peak force can be determined from the histogram.

It is anticipated that data produced with the IST will enable designers to select pick types, spacing, lacing, depth of cut, and rotary speed for specific coal types and seam conditions to improve cutting performance. In preliminary field tests already completed, one operator indicated a 15-pct increase in productivity by reorienting direction of cutting in the seam. While the Bureau is not yet ready to make such claims, since the device is still a research tool, it is already apparent the IST has great potential for helping operators improve the coal-machine interface to properly match machine characteristics to the seam characteristics.

DIGITAL ACQUISITION SYSTEM

A Digital MINC II system is available for data acquisition, processing, and storage. The system is based on the PDP-11/23[8] processor with the KEF11 floating-point chip. Peripheral storage is provided by a dual drive RX02 floppy diskette system and a dual-drive RL02 hard disk system. A total of 21 M bytes of random access storage is provided. User interaction with the system is through a VT105 video graphics terminal. Hard copies of video displays can be made on a Tektronics model 4632 device. Interfacing with the system is accomplished through RS232C ports, an IEEE instrument bus, and MINC input-output modules.

[8]The terms "PDP," etc., are the manufacturer's terminology and have no spelled-out equivalents.

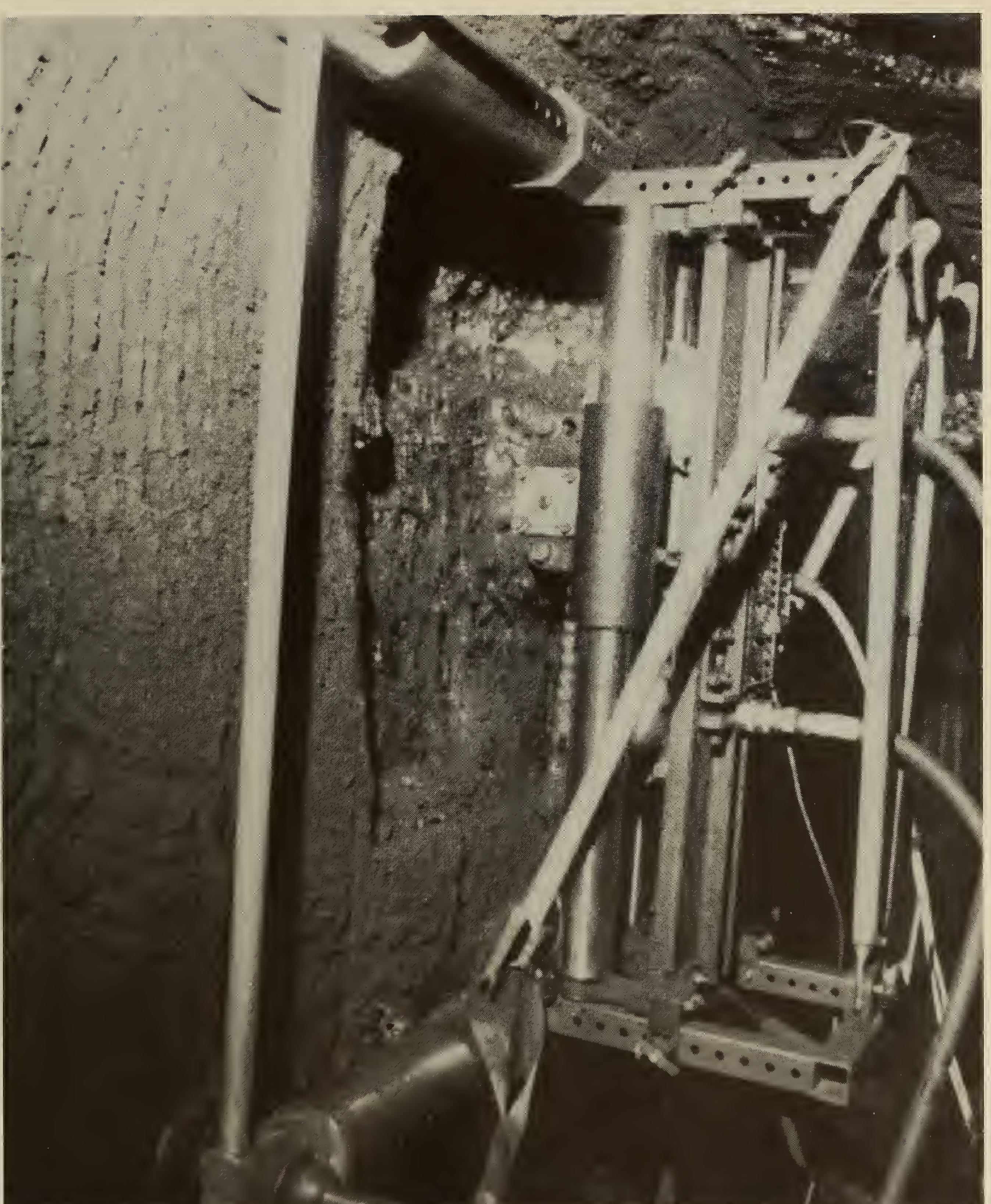

FIGURE 25. - In-seam tester cutting coal underground.

FIGURE 26. - Face area underground after testing with in-seam tester.

The modules presently include an A/D converter, a preamplifier, and a programmable clock. The system operates on MINC basic V.2.0, which includes routines for data acquisition and analysis, graphics, and IEEE bus support.

SAMPLE PREPARATION

COAL

The need for a constant supply of test samples requires both field acquisition and synthetic coal preparation. Field samples are sent to the Bureau; each is usually encased in gypsum for easy storage and handling, and to allow a stiff mounting in the cutting fixture, or to hold it at the proper bedding plane orientation. The coal soon changes from its in situ condition after it is left exposed in the laboratory environment. For further protection, the encased coal is stockpiled in a 90-pct-humidity room; as an alternative, raw coal may be immersed in water until needed. It will then be encased in gypsum 15 to 30 days before testing. Gypsum is used as the encapsulating material because the form used neither contracts nor expands on setup, which prevents adding unknown triaxial loads to the sample.

The coal to be encased in gypsum usually must be trimmed with a wire saw to fit in one of the forms. Those samples immersed in water are not trimmed for the form until they are ready to be used. When a coal sample is going to be used for cutting tests, one face of the gypsum block is cut off about 1 in back, and the block is turned 90° and sawed lengthwise down the center. The coal is then held

in a gypsum block with flat sides and ends for rigid mounting in the test fixture, but the top and front face are open for test cuts at the proper bedding orientation. The coal samples are usually not cut open until the day before testing. New raw coal is obtained about every 6 months.

SYNTHETIC SAMPLES

To perform full-scale cutting tests in the laboratory, large coal samples would be required. It is not practical to obtain such samples since they tend to break during acquisition or transport. Also their acquisition disrupts mine operation. Large samples also tend to deteriorate rapidly in the laboratory. Simulated coal avoids all of these difficulties. It is made in blocks shaped to fit the test facility. Unlike coal, they have a uniform matrix, which allows for consistent testing. The best simulation material found to date is a modified gypsum or plaster mix.

The physical characteristics of simulated coal are wide ranging, so the material can be tailored for specific characteristics. The strength can be varied by varying the mix. By reducing the mixing water, the brittleness of coal is approached, whereas increasing water lowers strength and reduces brittleness. Major cleating in the sample is a third coal characteristic; however, this is very difficult to reproduce and is not yet fully refined.

When mixing and pouring any simulated material, great care must be used in following the recipe. Since little water is used, the plaster must have retarders and water reducers in the proper proportions to allow a complete and easy pour before the material sets up. Following this, the sample must be dried for about a month at 104° to 120° F to drive out all excess water and to obtain the desired brittleness.

EXPERIMENTAL DESIGN

The variability of coal and rock samples used in cutting tests places severe restrictions on the design of the experiments. A standard bit (a plumb bob with a 60° included-angle carbide tip) is always included in each experiment for direct comparative reference. Owing to the extremely variable nature of the test materials, experimental results are treated as relative rather than absolute values.

The size limitations of the sample blocks preclude performing an entire experiment on a single one. Since the blocks' responses vary, sometimes substantially, the experimental design must incorporate the block differences. Block confounding and incomplete block designs are the most common methods used at TCRC to eliminate these effects. Hicks (5), Peng (8), and Davies (2) provide background for these and other methods. These methods do restrict the choice and range of variables that can be selected. In block confounding, the independent variables (e.g., cut depth, attack angle, bit type) must all have the same number of levels, i.e., there must be equal depths, angles, and types. With incomplete block designs, only one independent variable can be tested in an experiment. An example is found in the experimental design for the asymmetric wear study (10).

SUMMARY

The Bureau of Mines cutting technology facility at TCRC has the equipment for a broad range of mineral fragmentation research with mechanical cutting tools. The equipment permits research from the fundamental aspects of cutter geometry and primary dust generation to the applied studies of bit rotation, optimum depth of cut, and spacing. The facility is constantly changing to meet new research challenges, so the material described in this publication represents only the present situation. TCRC works closely on cooperative programs with industry, and equipment is often modified to meet specific needs.

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APPENDIX.--SPECIFICATIONS OF MAJOR COMMERCIALLY AVAILABLE TEST EQUIPMENT COMPONENTS

Small Linear Cutting Test System

Table working surface........................	30 by 40 in (76.2 by 101.6 cm).
Traverse range............................	24 in (60.96 cm).
Rate range per minute......................	0.6 to 24 in (1.42 to 60.96 cm).
Rate steps available......................	16.
Maximum cutting force........................	4,000 lb (17.8 kN).
Maximum depth of cut.........................	1-1/2 in (3.81 cm).
Main drive motor.............................	7-1/2 hp (3.81 cm).
Net weight...................................	5,050 lb (2,293 kg).

Large Linear Cutting Test System

Table working surface........................	40 by 128 in (101.6 by 325.1 cm).
Traverse range............................	118 in (299.7 cm).
Rate range per minute......................	1-15/16 to 62 in (4.92 to 157.48 cm).
Rate steps available......................	16.
Maximum cutting force........................	Over 6,000 lb.
Maximum depth of cut.........................	4 in (10.16 cm).
Main drive motor.............................	10 hp.
Net weight...................................	97,000 lb (44,038 kg).

Vertical Slotter Test System

Ram (cutter) stroke range....................	3 to 22 in (7.62 to 55.88 cm).
Cutter speed range...........................	25 to 100 ft/min (0.76 to 3.05 m/min).
Table diameter...............................	28 in (71.1 cm).
Table to lower face of ram (maximum).........	44-1/2 in (113 cm).
Table traverse--crossfeed distance (maximum).	24 in (60.96 cm).
Table traverse--longitudinal distance (maximum).................................	32 in (81.28 cm).

Ram angular forward adjustment.............. 0° to 10° C.

System has an automatic rotary table capability.

Maximum rated cutting force at slow speed.... 11,000 lb (48.9 kN).

Main drive motor............................ 10 hp.

Net weight.................................. 14,200 lb (6,447 kg).

<u>Three-Axis Dynamometer for Large Linear Cutting System</u>

Horizontal (tangential) and normal cutting forces--FZ, FY (maximum).................. 18,000 lb (80 kN).

Lateral force--FX (maximum)................. 2,000 lb (8.89 kN).

Crosstalk................................... Less than 5 pct.

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